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Shell Thickness Design Optimization of Bio digester Tank for Organic Waste Power Plants in Tegal Regency

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Abstract

Biogas is a renewable energy, produced from the decomposition of organic waste in an anaerobic environment and made in bio digester tanks. This research was conducted to design a biogas digester in a capacity of 1000 m^3 based on the dimensions of the tank, thickness of the shell plate, calculate the electrical power produced by biogas and also to calculate feasibility study. This experiment was performed using manual calculations, compared to API 650 and ASME VIII calculations. The results are then verified using tank design software. The results showed that the diameter, height and shell thickness of the tank base for 1000 m^3 capacity were 11500 mm, 10800 mm and 10 mm respectively. The first shell plate thickness was 10 mm, the second and third shell plate thickness is 8 mm, while the fourth and fifth shell plate thickness was 6 mm. The minimum thickness of the roof plate was 6 mm. The amount of electricity produced was 3.05 MW/hour. This study conclude that the design produced effective design so that the cost of purchasing plates becomes more economical.

Key-word: - Biodigester Tank, Tank Dimension, Shell, API 650, ASME VIII.

INTRODUCTION

Waste management has now become a problem in every city and district in Indonesia. In 2016, 21.5% of waste in Tegal Regency is organic waste. Tegal Regency use an open dumping system to manage waste. The advantages of this method are cheap and simple. However, on the other hand it can cause spreading foul odors, contaminates groundwater and provides the area for germ, viruses, and vermin so it becomes the source of many diseases [1].

The limitation of the open dumping system to manage a huge volume of solid waste and the increasing demand for renewable energy sources, especially in Tegal Regency, has led to implementing a biogas system. The use of organic waste in the biogas system works by anaerobically process on a reactor tank or called a biodigester tank. Based on research conducted by Abdul Muiz et al, the potential of waste in 2016 in Tegal Regency is 458 m^3 x 21.5% = 98.47 m^3 / day. This amount is equivalent to 758,219 m^3 / week. It means that a biodigester tankwith 750 m^3 - 1000 m^3 is required to accommodate garbage for 1 week [1].

LITERATURE REVIEW

Storage tanks are container that hold fluids such as gas, oil, water until the liquid mixes with solids such as porridge. The tank size is usually quite large (built on the project site) and used for low pressure (atmosphere). Tanks are also known as Atmospheric Tanks. According to the American Petroleum Institute (API) [2], the major design code for welded atmospheric tanks are API 650 and API 620. API 620 applies to tanks operated at internal working pressure (internal operating pressure) between 2-1/2 Psig to 15 Psig, and at temperatures not greater than 121.1ºC (250ºF) [3]. API 650 applies to tanks operated at internal working pressure (internal operating pressure) up to 2-1/2 Psig, and at temperatures not greater than 93.3ºC (200ºF).

Biodigester is a system used to accommodate and accelerate the decay of organic matter. From the biodigester, biogas and other compounds will be formed through anaerobic decay. Biogas can be used for cooking fuel, electricity generation fuel and engine fuel. Biogas raw materials can come from organic waste, so biodigesters can be one of the best alternatives to reduce the amount of waste. Examples of biodigester tanks can be seen in the following figure [4], [5], [6]:

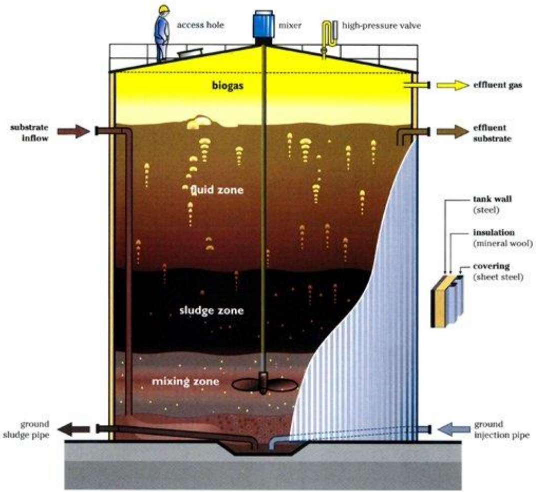


Figure 1. Biodigester Tank

Stress and Strain

In order to be able to withstand tank pressure, the thickness of the shell plate used must be calculated. The basic calculation formula used is the stress and strain formula [7]:

$$\sigma = \frac{F}{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(2.1)$$

Where :
σ = Stress (N/mm^2 atau MPa)
F = Force (N)
A = Area (mm^2)

As long as the force (F) work on the object does not exceed its elasticity limit, then the ratio between stress (σ) and strain (ε) is constant. These numbers (constants) are called elastic modulus or Young modulus (E).

$$\varepsilon = \frac{\Delta x}{A} \text{ dan } E = \frac{\sigma}{\varepsilon} \ldots\ldots\ldots\ldots\ldots\ldots..\ldots(2.2)$$

Where :
ε = Strain (tanpa satuan)
Δx = Delta Length (mm)
x = Length (mm)
E = Modulus Young (Elastic Modulus) (N/mm^2 atau MPa)
σ = Stress (N/mm^2 atau MPa)

API 650

API is the American Petroleum Institute [2]. Storage tanks design uses API 650. API 650 applies international design code and standard for tanks operating at internal operating pressure up to 2-1/2 Psig (18 KPa), and at temperatures not greater than 93.3ºC (200ºF).

Shell thickness calculations based on API 650 can be done with the following formula [8]:

$$t_d = \frac{4.9 \text{ x } D \text{ x } (H' - 0.3) \text{ x } G}{S_d} + CA \text{……......(2.3)}$$

$$t_t = \frac{4.9 \text{ x } D \text{ x } (H - 0.3)}{S_t} \text{ ………………......(2.4)}$$

Where :
td = Design shell thickness (mm)
tt = Hydrostatic test shell thickness (mm)
Sd = Allowable stress for the design. condition (MPa)
St = Allowable stress for the hydrostatic test condition (MPa)
D = Nominal diameter of tank (m)
P = Design Pressure (mAq atau KPa)
Pt = Hydrostatic Pressure = 1.25P, (mAq)
H = Height from bottom of course under consideration to design liquid level (m).
H’ = Height from bottom of course under consideration to design liquid level including design internal pressure (m).
H' = H + P/G.
G = Design specific gravity of liquid to be Stored.

ASME VIII

ASME is the American Society of Mechanical Engineers. Pressure vessels design is ASME Part VIII Division 1.2 and 3. According to ASME, pressurized tanks are divided into two categories: pressure vessels which are operated at pressures greater than 15 Psig and low-pressure vessels, operated at 15 Psig or less [9], [10].

Calculations based on ASME VIII can be done with the following formula:

$$t = \frac{P \text{ x } R}{((SxE) - (0.6P))} \text{ ...……...….……….(2.5)}$$

Where :
t = Shell thickness (inch)
P = Design pressure (Psi)
S = Stress value of material (Psi)
Material A283 Gr.C 13800 (Psi)
E = Joint efficiency
R = Inside radius (inch)
D = Inside diameter (inch)
CA= Corrosion allowance (mm)

RESEARCH METHOD

The research conducted to optimize the shell thickness of biodigester tank with 1000 m^3 capacity. Analysis was carried out by comparing plate thickness results from calculations based on stress and strain, API 650, ASME VIII and the results of design modeling using tank design software [11], [12]. At the time of calculation and modeling, the most optimal shell thickness was sought and compared to the existing research, so shell thickness optimization for biodigester tanks was obtained. Previous research showed that shell thickness 38 mm for a capacity of 2,717.74 m^3, diameter of 14.37 m and height of 17.96 m, in the operation pressure 1 atm [13]. To assess whether a design or project is feasible or not, a capital budgeting analysis is necessary. The main analysis is done on Payback Period (PP) and Internal Rate of Return (IRR) [14], [7]

Tools and Materials

The tool used to make the design is a PC / Laptop with Microsoft Excel software. The basis of the calculation refers to the Stress Strain, API 650 and ASME VIII and is combined with several books and journals that are in accordance with the research topic. Research data processed with a PC / Laptop.

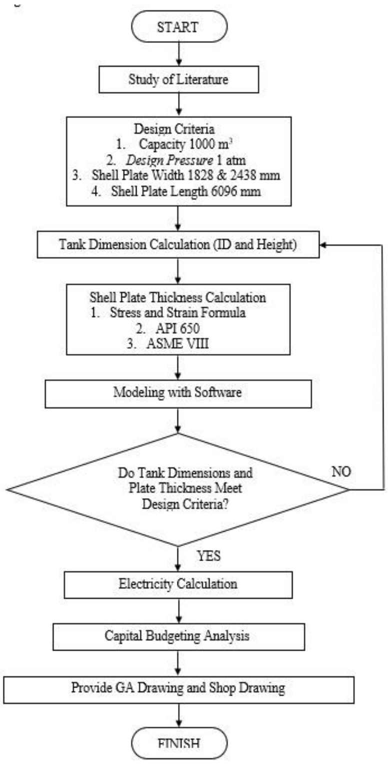
Figure 2. Code and Standard Design [9], [8]

Stages of Research

The research was conducted in five stages.

1. Literature Study
2. Determination of Design Criteria
3. Calculation of Tank Dimensions and Shell Thickness
4. Modeling with Software
5. To Calculate Electrical Power that Produced

Research Diagram



RESULTS

Tank Dimension Calculation (ID X H)

The base used to determine of the tank dimension is production of organic waste then matched with table A on API 650 attachment A and a combination of the plate dimension on the market. This method can reduce cost for purchasing plate to be minimal. The storage tank construction cost is become economical too [15], , [17].

Table 1. Capacity of Biodigester Tank

Capacity 1 x 1000 m^3							
Vc	=	Vc	=	0.15 x V	=	150	m^3
Vgs	=	Vgs +Vf	=	0.8 x V	=	800	m^3
Vf	=		=		=		m^3
Vs	=	Vs	=	0.5 x V	=	50	m^3
Total Volume						1000	m^3

Table 2. Plate Dimension (Width & Length)

Width & Length	**Usable**
Width 5ft (1524 mm)	1510 mm
Width 6ft (1828 mm)	1810 mm
Width 8ft (2438 mm)	2420 mm
Length 20ft (6096 mm)	6080 mm
Length 30ft (9144 mm)	9100 mm

Calculation of Shell Tank Thickness (ID X H)

Comparison of shell thickness calculation results can be seen in figure 2 below.

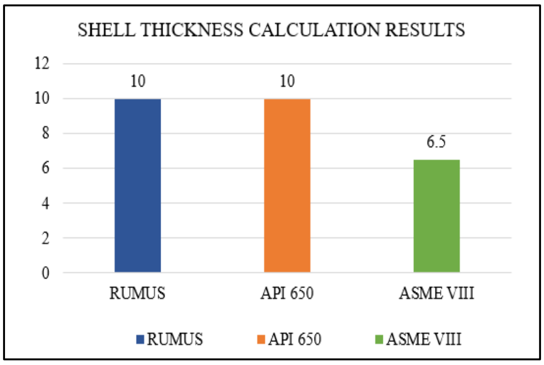


Figure 2. Shell Thickness Calculation Results (mm)

Modelling with Software

Shell thickness modelling results with software can be seen in Table 3. [18], [19]

Table 3. Modelling Software Results.

Shell	Shell Width (mm)	Height (H) (mm)	Desain Thick (td) (mm)	Hyd Test Thck (tt) (mm)	Used Plate Thck (mm)
1	2.40	10.8	8.23	3.76	10
2	2.40	8.4	7.24	2.89	8
3	2.40	6.0	6.26	2.01	8
4	1.80	3.6	5.27	1.13	6
5	1.80	1.8	4.53	1.13	6

After doing the calculation, the tank can be modelled as shown in figure 3 below. The results between calculations with software modelling can be seen in Figure 4 below. Based on the image the difference between calculation and modelling is very close.

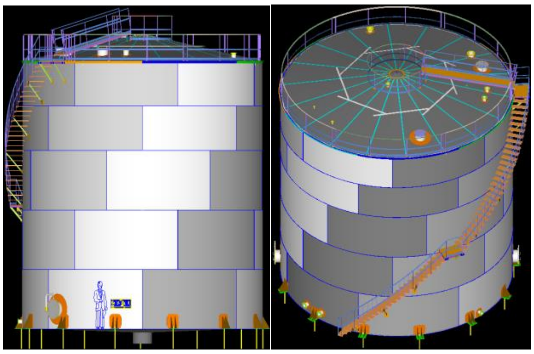


Figure 3. Front View & Upper View Modeling Software Results. [11]

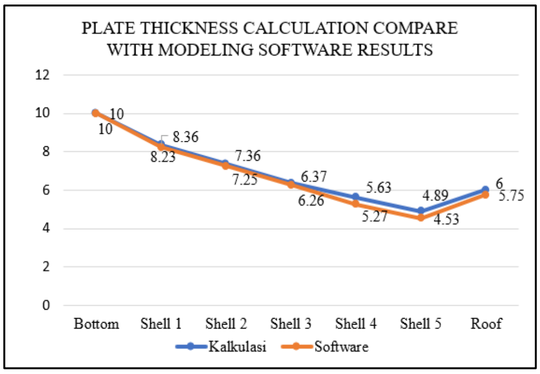


Figure 4. Shell Thickness Comparison Between Calculation & Software (mm)

Electricity Calculation

Municipal Waste / day
= 458 ton/day
Organic Waste / day (21.5%)
= 98.47 ton/day
Organic Fraction
= 98.47 ton/day
= 98,470.0 kg/day

Decomposition Efficiency of Bio digester [14]	= 60	%
Produced Biogas	= 59,082.0	m^3/day
Methane 60% from biogas 90%	= 38,403.30	m^3/day
Heating Value of Biogas [14]	= 5.6	kWh/m^3
Potential Production of Electricity Per Day	= 215,058.48	kWh/24 Hour
Power of the Biogas Power Plant	= 8,960.77	kW
	= 8.98	MW
Biogas Engine Generator Efficiency [7]	= 34	%
Potential Sales of Electricity	= 3.05	MW/Hour
	= 73.12	MW

Shell Thickness Optimization

In a design a portable type biogas reactor from cattle manure using fiberglass reactor [20], the highest pressure was at 101,933 N/m^2. The pressure rises around 0.089 Psig (0.607 KPa) from atmospheric conditions. This is in accordance with the research conducted by Senafati [13], the design pressure of the Carbon Steel A-285 Gr.C fermentation reactor using 1 atm. The average pressure increase in the biodigester tank is still below 2.5 Psig (18 KPa) so that the calculation of shell thickness is carried out using the API 650 instead of ASME VIII. Based on these conditions, the author determines the design pressure of a biodigester tank is 1 atm.Senafati, 2011 [13] conducted a study on the manufacture of Compressed Natural Gas (CNG) from biogas from thermofilic fermented palm oil waste with a capacity of 60 tons / hour. In this study using the Carbon Steel A-285 Gr.C fermentation reactor. The reactor has a capacity of 2,717.74 m^3, a diameter of 14.37 m, a height of 17.96 m, operating pressure 1 atm. This reactor used 1.5 in (38 mm) plate.

The calculations are made by the author using the API 650 with Carbon Steel A-283 Gr.C material (seen in table 4). The result of the calculation shows the first shell thickness is 10 mm. The second and third shell thickness is 8 mm. The fourth and fifth shell thickness is 6 mm. This method of calculation based on API 650 is in accordance with research conducted by Atrasani et al., 2017 [21] in his research titled design and modeling a 50,000 KL storage tank.

Based on these conditions the calculation of plate thickness based on API 650 is more optimal because the thickness of the shell plate can be more economical. Of course, the plate thickness is very influential on the price of the plate to be used. So, the cost of making a biodigester tank becomes more economical while still fulfilling the applicable code and design standards.

Table 4. Shell Thicknes Optimization Results.

S	Shell Width (mm)	Height (H) (mm)	Desain Thck (td) (mm)	Hyd Test Thck (tt) (mm)	Plat Thck In the Market (mm)	Plat Thck Optimi-zation (mm)
1	2.40	10.8	8.23	3.76	8 & 10	10
2	2.40	8.4	7.24	2.89	6 & 8	8
3	2.40	6.0	6.26	2.01	6 & 8	8
4	1.80	3.6	5.27	1.13	4 & 6	6
5	1.80	1.8	4.53	1.13	4 & 6	6

Analisis Capital Budgeting

- Payback Period (PP)

Payback Period can be calculated from the initial investment cost divided by the average incoming cash flow. The details can be seen in the following calculation. [15], [22], [7]

Initial Investment Cost = Rp 35,680,978,703.50
Average Cash Flow = Rp 15,856,043,822.30

$$\text{PP} = \frac{\text{Rp } 35{,}680{,}978{,}703.50}{\text{Rp } 15{,}856{,}043{,}822.30} = 2.25 \text{ Years}$$

Based on tis calculation, the value of the Payback Period is 2.25 years. Hopefully the investment can be returned in 2.25 years. This is very interesting investment. [15], [22], [7]

- Internal Rate Return (IRR)
  Internal Rate Return can be calculated from [15], [22], [7]:

$$IRR = 30\% + \frac{18{,}477{,}205{,}078.94}{(18{,}477{,}205{,}078.94 - 127{,}966{,}798.75)}(40\% - 30\%)$$

$$IRR = 40.1\%$$

Internal Rate Return value is 40.1%. This IRR value is still higher than the interest in saving money in a bank. Based on these conditions, this business is feasible.

CONCLUSION

After carrying out the stages of research and design simulation it can be concluded:

1. Economical dimensions for 1000 m^3 capacity are ID = 11500 mm and H = 10800 mm.
2. The shell plate thickness used is as follows:
   The 1st shell plate thickness is 10 mm
   The 2nd and 3rd shell plate thickness is 8 mm
   The 4th and 5th shell plate thickness is 6 mm
3. The picture of the construction of the bio digester tank has been made and can be directly applied.
4. The amount of electricity generated is 3.05 MW / hour.
5. This business has a Payback Period (PP) at 2.25 years and an IRR of 40.1%. The IRR value is still greater than the interest of saving money in the bank, so this business is feasible.

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